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SUMMARY

An evaluation of an instrument display incorporating a moving-map instrument has been conducted in landing-approach tests with a helicopter. The display consisted of the map instrument, a vertical-situation indicator, and vertical-scale instruments for the indication of airspeed, vertical speed, and height. The tests were conducted under simulated IFR (Instrument Flight Rules) conditions along a 6° glide slope at approach speeds of 30 knots. Winds near the ground were about 8 knots.

Tests of four maps with scales ranging from 100 to 1000 ft/in. (12 to 120 m/cm) showed that the pilots were able to adapt and to perform effectively with any of the scales tested. For the final part of the approach, however, their tracking performance was better with maps having large scales (on the order of 100 ft/in., or 12 m/cm). With two of the larger-scale maps, approaches were flown to a 50-foot (15.24 m) breakout and visual slowdown to hover.

The pilots were of the opinion that the map instrument provides a realistic display of course guidance information that can be interpreted easily and used with confidence.

INTRODUCTION

With present cockpit instrument displays, landing approaches of helicopters under IFR (Instrument Flight Rules) conditions are restricted to breakout ceilings (altitude for transition from instrument to visual flight) of 200 feet (60.96 m) and higher. If helicopters and other V/STOL aircraft are to operate to lower ceilings, improved instrument displays will be required, whether the aircraft are flown manually or controlled by automatic systems. In the latter case, improved displays would still be required for monitoring the progress of the approach. In an effort to determine the instrument display requirements for landing approaches of V/STOL aircraft to very low ceilings (and ultimately to touchdown), the NASA is evaluating a variety of instrument displays, using a helicopter as the test vehicle.

With the first display tested in the program (ref. 1), the information for slope and course guidance was presented on a conventional vertical-situation indicator (VSI) and a conventional horizontal-situation indicator (HSI). Of the two course-guidance concepts tested with this display – (1) flight-director command on the VSI and (2) course deviation supplemented by ground-track angle on the HSI – the flight-director command was found to provide the more precise steering information.

In the tests of the second display, which are reported herein, the HSI of the first display was replaced with a moving-map instrument. The map instrument presents a combined indication of course deviation, range, and relative heading, and the movement of the map provides qualitative indications of ground speed and ground-track angle.

The second display was tested in the same helicopter as the first and by the same test pilots. The flight task was also the same; namely, a 30-knot simulated IFR approach along a 6^0 glide slope to a 50-foot (15.24 m) breakout. For the evaluation of the map display, approaches were made with four maps with scales ranging from 100 to 1000 ft/in. (12 to 120 m/cm).

The results of the evaluation are presented in terms of pilot performance and pilot opinion. The results are also compared with those obtained with the flight-director steering of the first display.

SYMBOLS

d_s proportionate slope deviation, $\Delta z/w_s$

w_s slope width from slope center line, displacement from slope for full-scale deflection of ILS slope-deviation indicator, feet (meters)

x range, distance of aircraft from slope origin as measured in ground plane, along or parallel to course, feet (meters)

$\dot{x}$ longitudinal velocity of aircraft, knots

y course deviation, lateral displacement of aircraft from selected course, feet (meters)

z height of aircraft above ground plane, feet (meters)

Δz slope deviation, vertical displacement of aircraft from glide slope, feet (meters)

$\dot{z}$ vertical velocity of aircraft, feet per minute (meters per second)

ψ relative heading, degrees

INSTRUMENT DISPLAY

The instrument display evaluated in the present investigation is shown in figure 1. The display consisted of a moving-map instrument, a vertical-situation indicator, vertical-scale instruments (for the indication of airspeed, vertical speed, and height), and a dial-type torquemeter.

Moving-Map Instrument

The moving-map instrument projects a map and an aircraft symbol (with axis extension line) on the rear face of an acrylic plastic screen (fig. 2) that is $7\frac{1}{2}$ inches (19.1 cm) wide by $5\frac{1}{2}$ inches (14.0 cm) high. The map moves laterally to indicate course deviation y and vertically to indicate range x; the aircraft symbol rotates to indicate heading ψ with respect to course.

The projected map is an 11.6 magnification of a micromap on a transparent film strip 4.5 inches (11.4 cm) wide by 20 inches (50.8 cm) long. The film strip is mounted on a drum (fig. 3) that rotates to produce lateral movement of the projected map and moves fore and aft to produce vertical movement. The translation and rotation of the drum are controlled by the x and y signals from a ground-based radar.

The sensitivity of the drum movements to the x and y inputs can be varied by adjustment of the airborne computer network to match the scale of the map. The x and y scale factors can also be changed (at a selected range) by an automatic increase in the gain to the drum's servomechanism. Because the fore-and-aft travel of the drum is limited to 3 inches (7.6 cm), the length of the displayed maps for the present investigation was limited to 35 inches (88.9 cm).

Vertical-Situation Indicator

The vertical-situation indicator was a standard roll-pitch indicator with cross-pointers which are normally used for the indication of slope and course commands (flight-director signals). Since, in the present investigation, course guidance information was to be derived from the moving-map presentation, the vertical (course command) needle was deflected from view. In addition, slope commands were not presented on the horizontal needle because, as noted in reference 1, slope control of a helicopter at low speeds (below that for minimum power) is accomplished by the control of power as well as airspeed, so that separate indications are required for the control of these two quantities.

The horizontal needle was therefore used for indications of pitch attitude (for airspeed control) and the vertically moving tab on the left of the instrument was used to indicate slope deviation (for power control).

Airspeed, Vertical-Speed, and Height Indicators

The vertical-scale instruments used for the indication of airspeed, vertical speed, and height were especially designed for the present display program. The instruments had fixed scales with moving pointers (triangles on the tapes) for the speed indicators and thermometer-type presentations for the height indicators. (See fig. 1.) The scale length of the indicators was 4.5 inches (11.4 cm) and the scale ranges were as follows:

Airspeed	0 to 100 knots
Vertical speed	-800 to 200 ft/min (-4.06 to 1.02 m/sec)
Height (fine)	0 to 275 ft (83.82 m)
Height (course)	0 to 1100 ft (335.28 m)

Because of limitations of the airspeed transducer and the pitot-static system at low speeds, the airspeed readings were unusable below 20 knots (as indicated by the cross-hatched area at the lower part of the airspeed scale).

The two white rectangles at the bottom of the scale of the 1100-foot (335.28 m) altimeter indicate the 275-foot (83.82 m) height at which the pilot should transfer his attention to the more sensitive height indicator. The two white triangles at the bottom of the scale of the 275-foot (83.82 m) altimeter indicate the height for the 50-foot (15.24 m) breakout.

GUIDANCE SYSTEM

The guidance system consisted of (1) a ground-based radar and associated computing equipment, (2) two telemetry systems, and (3) airborne discriminators and analog computers. A detailed description of the guidance system and its operation is given in reference 1.

The information generated by the guidance system for presentation on the test display included the quantities x, y, z, $\dot{z}$, and d_s, where d_s is the ratio of slope displacement Δz to slope width w_s at range x. The position of the landing-approach map in the map indicator was controlled by the x and y signals. The two height indicators were actuated by the z signal and the vertical-speed indicator by the $\dot{z}$ signal. The slope-deviation tab on the VSI was actuated by the signal d_s.

RECORDING INSTRUMENTS

Recording instruments were installed in the radar ground station and in the helicopter. In the ground station, coordinate plotters (x-y and x-z) recorded the horizontal and vertical tracks of the aircraft on 10- by 15-inch (25.4 cm by 38.1 cm) charts. Time histories of the quantities x, $\dot{x}$, y, z, Δz, $\dot{z}$, and d_s were also recorded. In the helicopter, NASA flight-test instruments recorded time histories of (1) airspeed and altitude, (2) the movements of the four cockpit controls, and (3) the deflections of the slope-deviation tab and the horizontal needle of the VSI.

The records of the airborne and ground-station recorders were synchronized by transmitting the ground-station timing signals to the airborne recorders. The records of the airborne and ground-station recorders could also be marked simultaneously (by radio link) at selected times (such as breakout and hover).

INSTRUMENT ACCURACIES

The accuracy of the ground-position indications of the map instrument was checked by hovering the helicopter over surveyed points along and to each side of the course. The data obtained with a map having a scale of 100 ft/in. (12 m/cm) for the final 2500 feet (762 m) of the approach showed that the error of the longitudinal position increased from near zero at the landing pad to 40 feet (12.20 m) at a range of 2500 feet (762 m); the error for a ±100-foot (±30.48 m) lateral displacement was essentially zero throughout the 2500-foot (762m) range.

On the basis of the calibrations that were performed for the tests of reference 1, it was determined that the accuracies of the quantities displayed on the vertical-situation and vertical-scale indicators were within the reading accuracies of the instruments.

The accuracies of the x-y and x-z plotters were found to be within the specified accuracies of the radar which, for the angular scanning ranges of the present tests, were as follows:

	1-sigma values
x	10 feet (3.05 m) or 1 percent (whichever is greater)
y	3 feet (0.91 m) at zero range 8 feet (2.44 m) at 7000-foot (2133 m) range
z	1 foot (0.31 m) at zero range 11 feet (3.35 m) at 7000-foot (2133 m) range

TEST AIRCRAFT

The test helicopter (fig. 4) for the present investigation was the same as that used for the tests of the cross-pointer display of reference 1. This helicopter was not equipped with artificial stabilization.

The test instrument display was located on the left side of the cockpit, directly in front of the pilot and more nearly at eye level than the service instrument panel. A corner reflector was installed on the nose of the fuselage to provide a point source for reflection of the radar beam.

Instrument flight conditions were simulated as in reference 1 by covering the windshield with amber plastic and having the pilot wear a special visor of blue plastic.

TEST PROGRAM

Approach-Path Patterns

The approach-path patterns used for the evaluation of the instrument display of the present investigation are shown in figure 5. These patterns were the same as those used for the tests of the display of reference 1 except for the terminal width of the course pattern, which was changed from ±75 feet (±22.86 m) to ±100 feet (±30.48 m) to correspond to the width of the runway at the test airfield.

Landing-Approach Maps

The landing-approach maps evaluated in the present tests are shown in figure 6. The dimensions of the maps as displayed on the screen are indicated by the scale on the left of the figure, and the portions of maps displayed at any one time are indicated by the diagram of the display screen. The scales of the maps, as indicated by the tabulated scale factors, range from 100 to 1000 ft/in. (12 to 120 m/cm).

Maps I and II are simply scaled drawings of the course pattern. Map III is a distorted view of the pattern because of the 2:1 ratio of the x and y scales. Map IV is a two-part map in which both x and y scales change, at a range of 2500 feet (762 m), by a factor of 10.

For hover trials, a special landing-pad map with a scale of 200 ft/in. (24 m/cm) was provided; this map is not shown in figure 6.

Approach Tests

The approach task for the present tests was the same as that used in the tests of reference 1; namely, an IFR approach along a 6° slope at a constant airspeed of about 30 knots (about 25 knots below the speed for minimum power). Each approach was started at a range near 10 000 feet (3048 m), below the glide slope and to one side of the course.

For an evaluation of map scale, the project pilot flew 10 exploratory approaches with each of the four maps to heights as low as about 25 feet (7.62 m), at which point the safety pilot took over the controls. To obtain performance data for comparison with the flight-director steering data of reference 1, the project pilot then flew 10 approaches with each of maps III and IV to a 50-foot (15.24 m) breakout and visual slowdown to hover.

In simulating the transition from instrument to visual flight, the pilot lifted his visor when the height indicator reached 50 feet (15.24 m); he then brought the helicopter to a hover along the course center line in as short a distance as possible.

In subsequent simulated IFR tests with the terminal chart of map IV, the project pilot made seven attempts to bring the helicopter to a stop over the landing pad. These approaches were started at a speed of about 30 knots, on the glide slope, and at a range of about 2500 feet (762 m). Using the special landing-pad map, the pilot made three attempts to hover for a period of about 1 minute over the center of the landing pad.

After the tests by the project pilot, the safety pilot, who had become familiar with the map instrument during the map-scale tests, flew 10 approaches to a 50-foot (15.24 m) breakout with each of maps III and IV. In a subsequent 1-day evaluation, a third pilot (who had no previous experience with the map instrument) flew 23 approaches with the same two maps.

The three pilots who participated in the present tests were the same NASA research test pilots who evaluated the display of reference 1.

RESULTS AND DISCUSSION

Evaluation of Map Scales

The results of the tests of the four approach maps (with scales ranging from 100 to 1000 ft/in., or 12 to 120 m/cm) showed that the pilot was able to adapt and to perform effectively (i.e., stay within the course boundaries) throughout the range of map scales. The tests also showed that the pilot was able to adapt to the 2:1 increase in the lateral scale of map III (despite the distortion of the indicated ground-track angles) and to the abrupt 10:1 change in the scale of map IV (despite the rapid increase in the rate of map movement).

In the initial 7500 feet (2286 m) of the approach there was no significant difference in tracking performance with different map scales; in the final 2500 feet (762 m) the tracking was noticeably better with the larger scales of maps III and IV. It would appear, therefore, that for the initial part of the approach, a scale as small as 1000 ft/in.

(120 m/cm) is satisfactory for guidance within a $\pm 3^{\circ}$ course pattern; for the final part of the approach, a much larger scale (on the order of 100 ft/in., or 12 m/cm) is needed for precise guidance within a ±100-foot (±30.48 m) terminal path. This finding is in general agreement with the results of previous tests of map scale in simulated helicopter approaches (ref. 2).

After his flights with the four maps, the project pilot stated his preference for map IV, with map III as a second choice. He liked the small longitudinal scale of the initial approach chart of map IV because it presented a larger view of the approach zone (during the time when he was occupied with intercepting the course, acquiring the slope, and stabilizing the approach speed); he also liked the large scale of the final approach chart because it provided a more precise indication of position and a better indication of speed over the ground. Of maps I, II, and III, the pilot preferred map III because of the large lateral scale, which he felt was needed for precise guidance in the final part of the approach.

Pilot Performance

In the performance tests by the project pilot, the 10 approaches with maps III and IV were all flown consecutively and under essentially the same wind conditions. The course and slope tracks for the approaches with map III are presented in figure 7, and those with map IV in figure 8. The course deviations and height are plotted to a scale five times the range scale, so the plotted tracks present a distorted picture of the actual tracks. The boundaries for the course and slope patterns are shown by dashed lines. The magnitude and direction of the winds near the ground are shown by the windspeed diagrams on the course plots; the vectors represent average values and the fluctuations about these values are noted alongside the diagrams.

From an examination of the course tracks it is apparent that for the initial part of the approach (to $x = 2500$ feet, or 762 m), the tracking with the two maps is about the same even though the lateral scale for map IV is about one-seventh that for map III. In the final 2500 feet (762 m), however, the tracking with map IV is generally better than with map III.

Since the success of a landing approach is determined largely by the slope and course deviations at breakout, the tracks in figures 7 and 8 were examined to determine the lateral and longitudinal deviations from the prescribed point for the 50-foot (15.24 m) breakout. These deviations are presented in figures 9(a) and 9(b). The lateral deviations with map IV are smaller than those with map III, and the longitudinal deviations (which are a measure of the slope deviations at breakout) are also smaller. With map IV, the lateral deviations were within 30 feet (9.14 m) and the longitudinal deviations within 160 feet (48.77 m); for a 6° slope, this longitudinal deviation corresponds to a slope deviation of

16 feet (4.88 m). From these results it would appear that the larger scale of the final approach chart of map IV permits better control of both slope and course near the 50-foot (15.24 m) breakout.

In the tests by the project pilot of flight-director steering in reference 1, the course tracking, for wind conditions comparable to those for the approaches in figures 7 and 8, was more precise than with the map instrument. In the final 5000 feet (1528 m) of the approach, for example, the course deviations (as shown by the course plots of ref. 1) were only about 50 feet (15.24 m), whereas those with map IV (as shown in fig. 8) were as large as 150 feet (45.72 m). At the 50-foot (15.24 m) breakout, however, the lateral deviations with map IV (fig. 9(b)) were as small (within ±30 feet, or 9.14 m) as those with the flight-director steering (fig. 9(c)).

Slope tracking and the control of attitude and airspeed with the instrument display of the present investigation were generally better than with the display of reference 1, even though the same instruments were used for slope guidance and for indications of attitude and airspeed. The improvement in the control of airspeed with the present display is shown in figure 10 by the time histories of the airspeeds for the 10 approaches with map IV, the tracks of which are shown in figure 8. These plots show that, in general, the variation in airspeed from the speed the pilot was attempting to maintain was about ±3 knots. With the display of reference 1, under essentially the same wind conditions, the airspeed variations, as shown by similar plots in reference 1, were about ±5 knots.

From a consideration of all the control tasks (course tracking, slope tracking, and the control of attitude and airspeed), the performance by the project pilot of the overall flight task was better with the present display than with the display of reference 1.

In the performance tests by the safety pilot, the 10 approaches with each of maps III and IV were all flown consecutively and to a successful 50-foot (15.24 m) breakout. The precision of the tracking (in both slope and course) was about the same as that shown in figures 7 and 8. The performance of this pilot with the present display was very much better than his performance with the display of reference 1.

In the tests by the third pilot (a 1-day evaluation of maps III and IV), the number of approaches flown to a successful 50-foot (15.24 m) breakout was less than that of the other two pilots. The performance of this pilot with the present display, however, was also better than with the display of reference 1.

In the attempts by the project pilot to slow down to a stop under simulated IFR conditions using the terminal chart of map IV, only about one-half of the approaches were brought to a successful stop, and these stopping points were generally about 100 feet (30.48 m) beyond the center of the pad. In the hover trials, it was found that the pilot was unable to hover over a point; during the 1-minute test period, the excursions from the hover point were as much as 100 feet (30.48 m). The lack of success in performing these slowdowns and hovers was due in part to the great difficulty in controlling the helicopter at very low speeds.

Pilot Opinion

The three pilots were all of the opinion that the map instrument provides a realistic display of ground position and relative heading that is easily and quickly interpreted. The pilots liked the ground-position plot because the precise indications of course deviations and range gave them a feeling of confidence in knowing their position in the approach zone; this assurance had the effect of reducing the mental part of the pilots' workload. The pilots also liked the rotating symbol-and-line presentation of relative heading because it provides a visual picture of the angle. After brief familiarization, the pilots found they were using the visual angle in preference to the numbered scale at the top of the screen. Because of the ease with which the course guidance information could be derived from the ground plot and heading presentations, the pilots felt they were able to spend more time on the control of speed, attitude, and slope.

The three pilots were also in agreement that the map instrument provides a better presentation of course guidance information than that provided by the flight-director command of the display of reference 1. Because of the nature of the flight-director command (which provides no information on lateral position but only indicates when a control correction should be made), the pilot is essentially constrained to follow the center line of the course. With the map instrument, on the other hand, the pilot knows his position with respect to the course boundaries and thus can decide whether he should correct for course or attend to the other control tasks. The map instrument, therefore, seemed to allow better distribution of the pilots' attention to the overall control task.

SUMMARY OF RESULTS

An evaluation of an instrument display incorporating a moving-map instrument has been conducted in a helicopter. The evaluation was made with four maps that had scales ranging from 100 to 1000 ft/in. (12 to 120 m/cm). The tests were conducted under simulated IFR (Instrument Flight Rules) conditions along a 6° glide slope at an approach speed of 30 knots. Winds near the ground were about 8 knots. From tests by three pilots, the following results are indicated:

1. The pilots were of the opinion that the map instrument provides a realistic display of course guidance information that can be interpreted easily and used with confidence.

2. The pilots were able to adapt readily and to perform effectively throughout the range of map scales tested; they were also able to adapt to a 2:1 increase in the lateral scale and to an abrupt 10:1 change in both lateral and longitudinal scales.

3. For the initial part of the approach, a scale as small as 1000 ft/in. (120 m/cm) is satisfactory for guidance within a $\pm 3^{\circ}$ course pattern. For the final part of the approach, a much larger scale (on the order of 100 ft/in., or 12 m/cm) is needed for precise guidance within a ±100-foot-wide (±30.48 m) terminal path.

4. Using a two-part map with a 1000-ft/in. (120 m/cm) scale for the initial 7500 feet (2286 m) of the approach and a 100-ft/in. (12 m/cm) scale for the final 2500 feet (762 m), two pilots each flew 10 consecutive approaches to a successful 50-foot (15.24 m) breakout and a visual slowdown to hover. In the tests by one of the pilots, the lateral deviations at breakout were within 30 feet (9.14 m) and the longitudinal deviations were within 160 feet (48.77 m). For a 6° slope, this longitudinal deviation corresponds to a slope deviation of 16 feet (4.88 m).

5. Attempts to slow down to a stop and to hover over a point under simulated IFR conditions were generally unsuccessful, in part because of the great difficulty of controlling the helicopter at very low speeds.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 16, 1967,
721-04-00-10-23.

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2. Dougherty, D. J.: Human Factors JANAIR Display Evalutions. Joint Army-Navy Aircraft Instrumentation Research Progress Report, Tech. Rept. No. D228-100-008 (Contract Nonr 1670(00)), Bell Helicopter Co., July 1963, pp. 23-63.

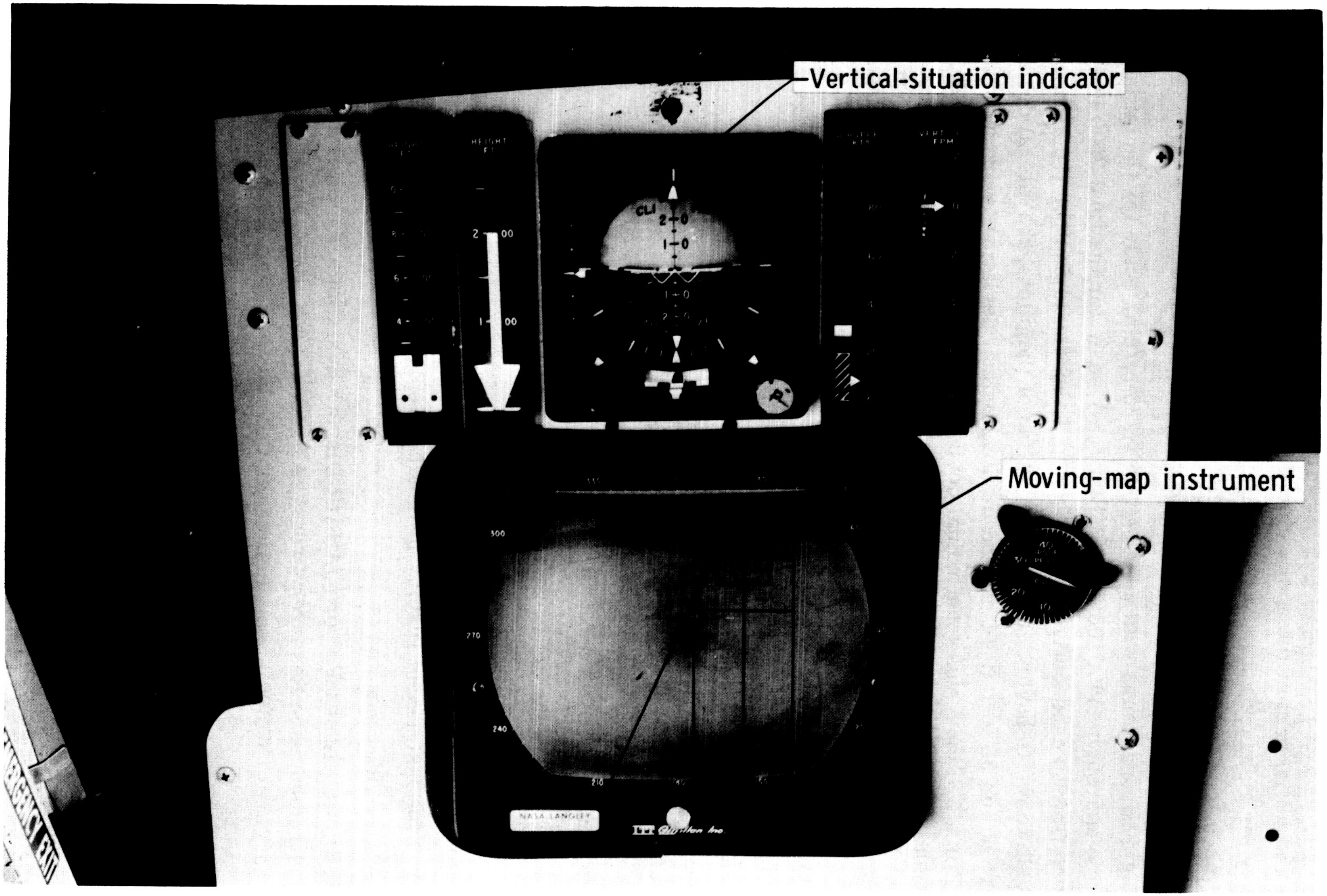


Figure 1.- Test instrument display.

L-66-6797.1

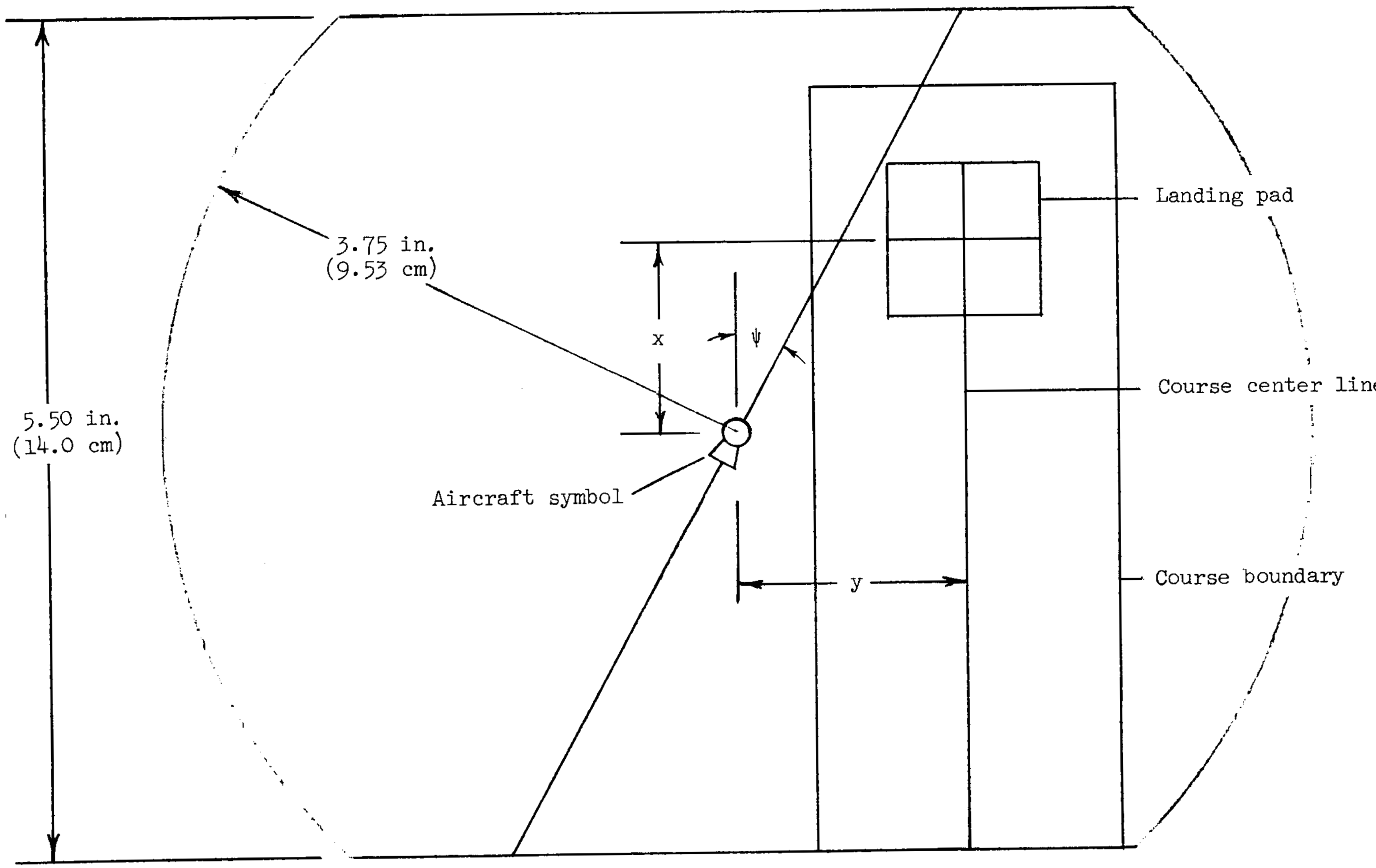


Figure 2.- Diagram of map projection on display screen.

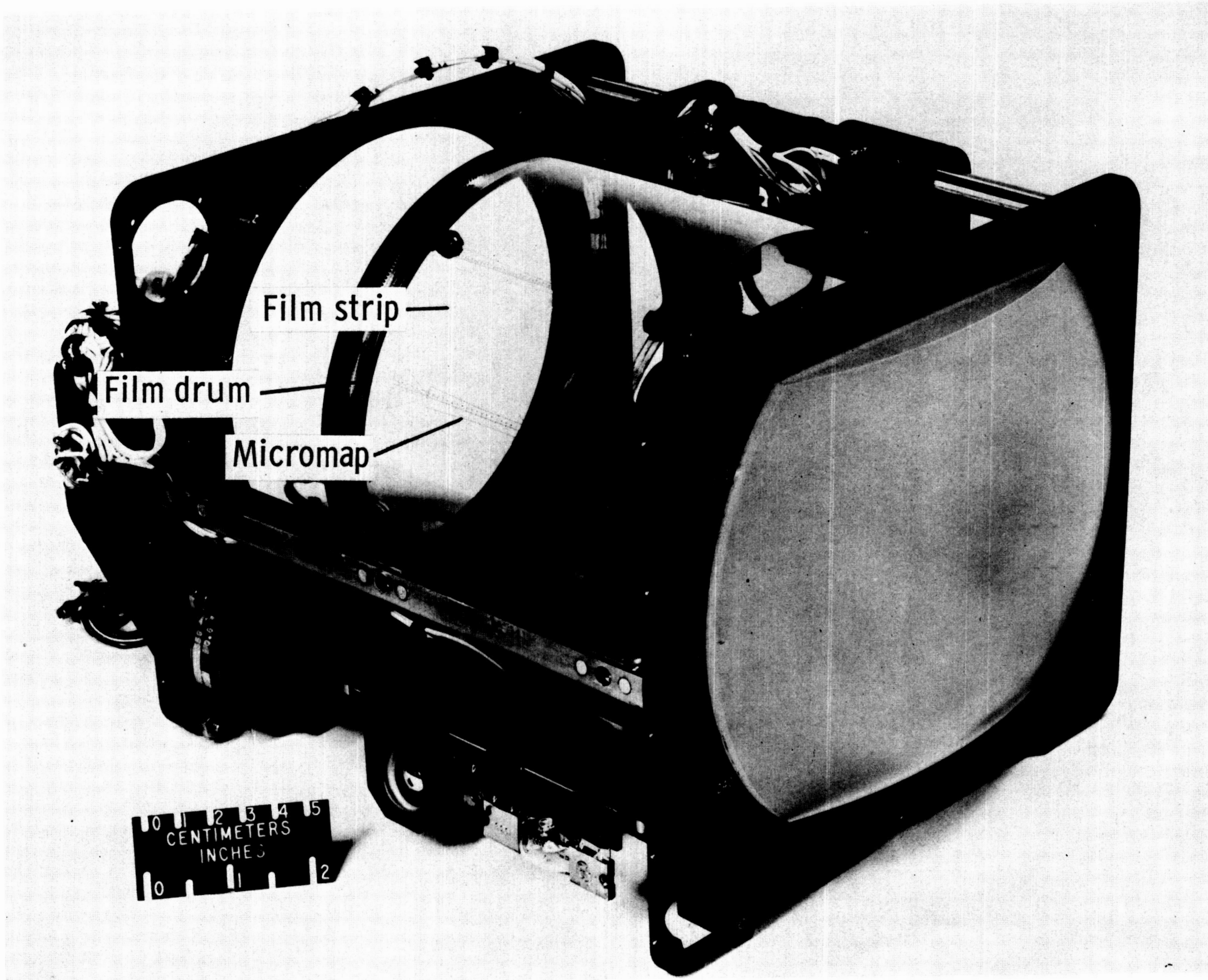


Figure 3.- Drum mechanism of moving-map instrument.

L-66-7331.1

Figure 4.- Test helicopter.

L-65-8688.1

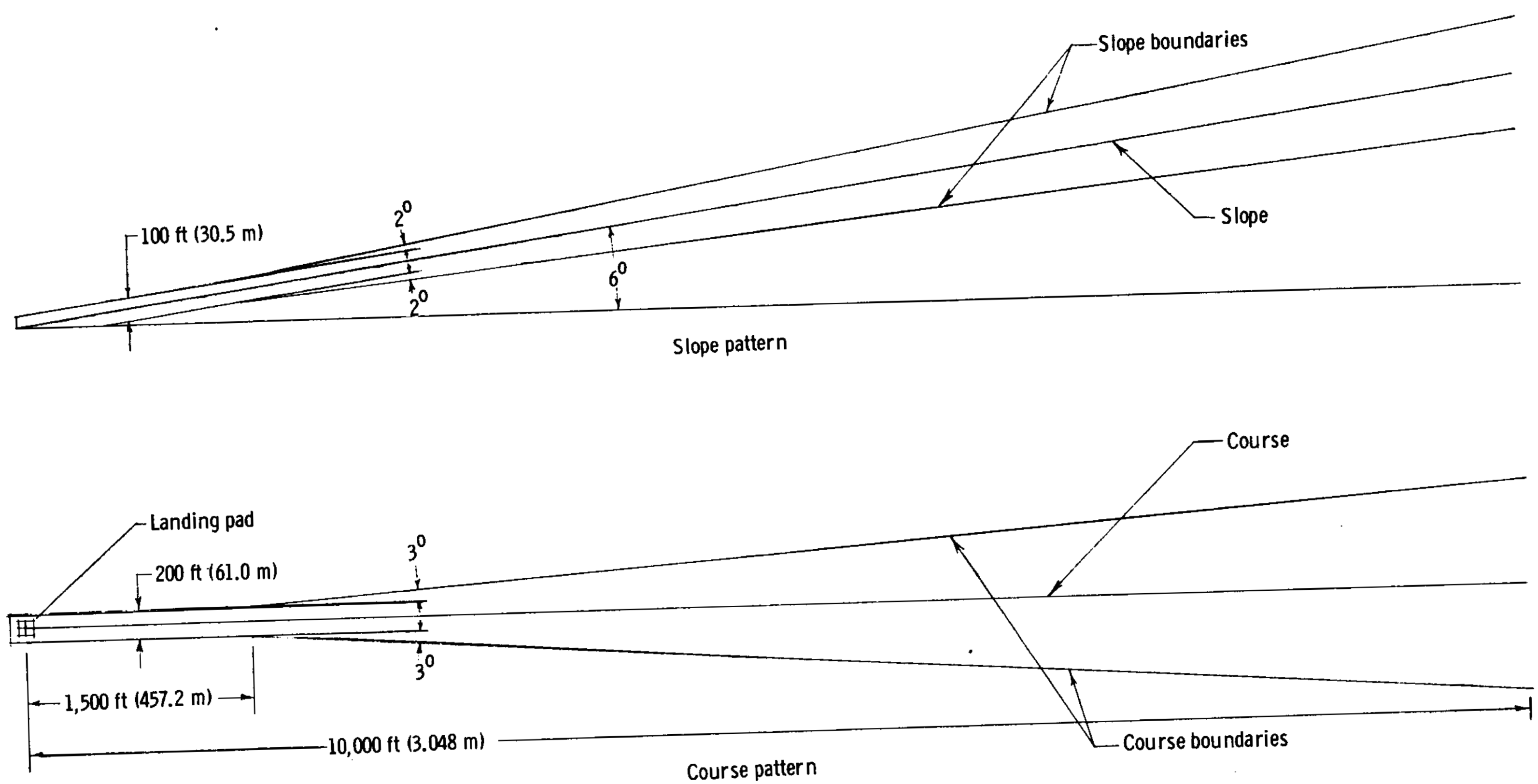
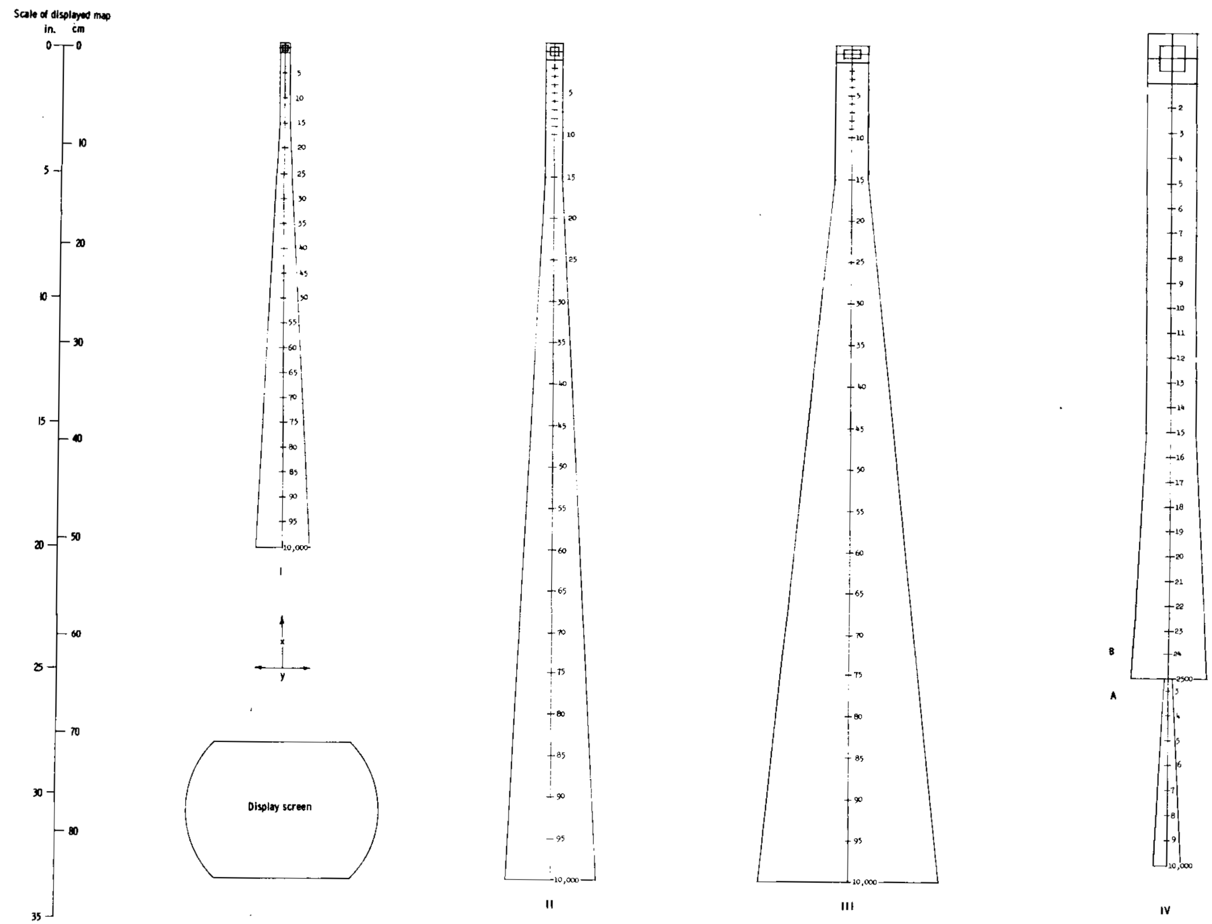


Figure 5.- Approach-path patterns.



Scale factors.

	I	II	III	IV A	IV B
x	500 ft/in. (60 m/cm)	300 ft/in. (36 m/cm)	300 ft/in. (36 m/cm)	1000 ft/in. (120 m/cm)	100 ft/in. (12 m/cm)
y	"	"	150 ft/in. (18 m/cm)	"	"

Figure 6.- Landing-approach maps tested in present investigation.

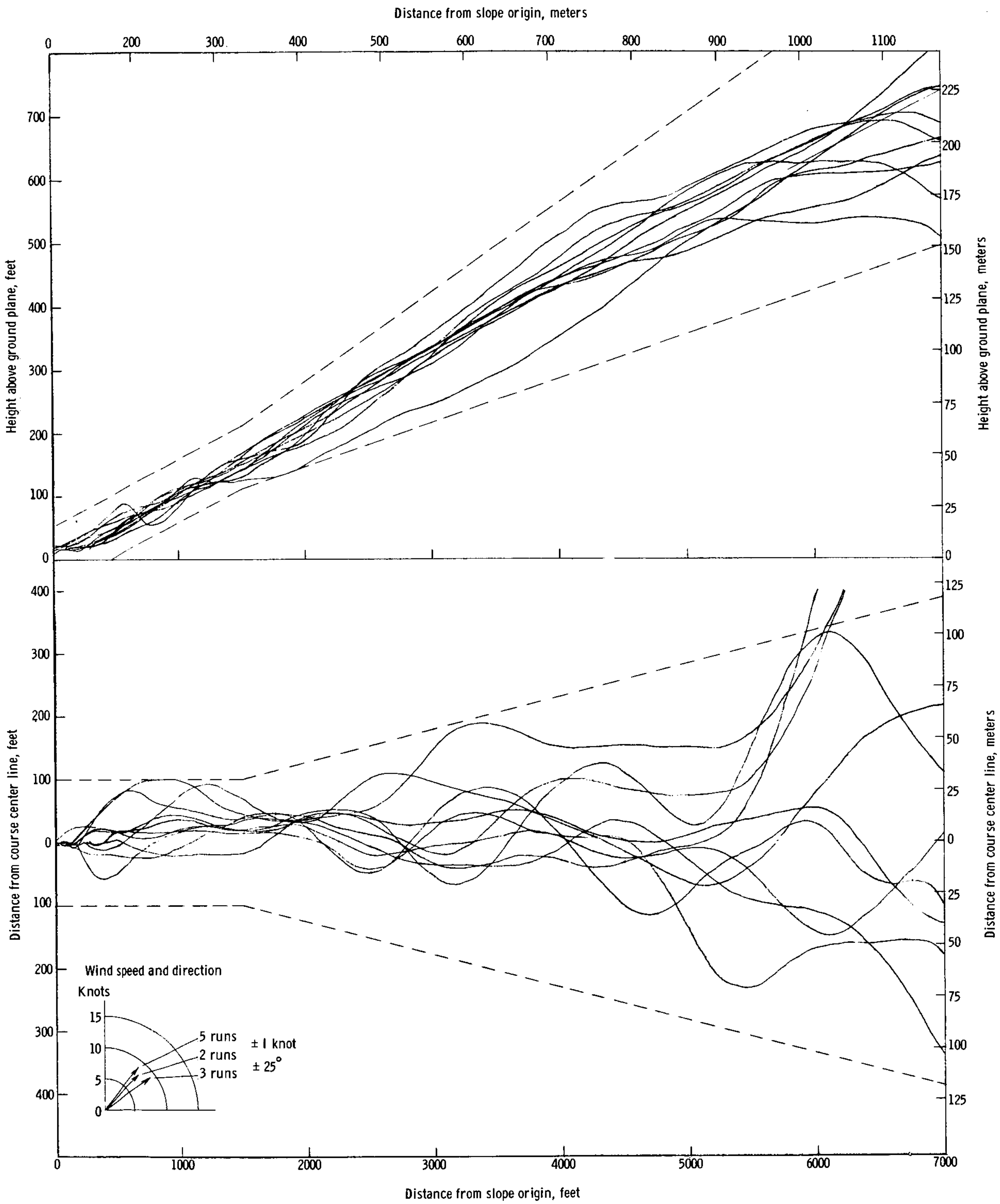


Figure 7.- Course and slope tracks for ten 30-knot approaches to 50-foot (15.24 m) breakout. Map III.

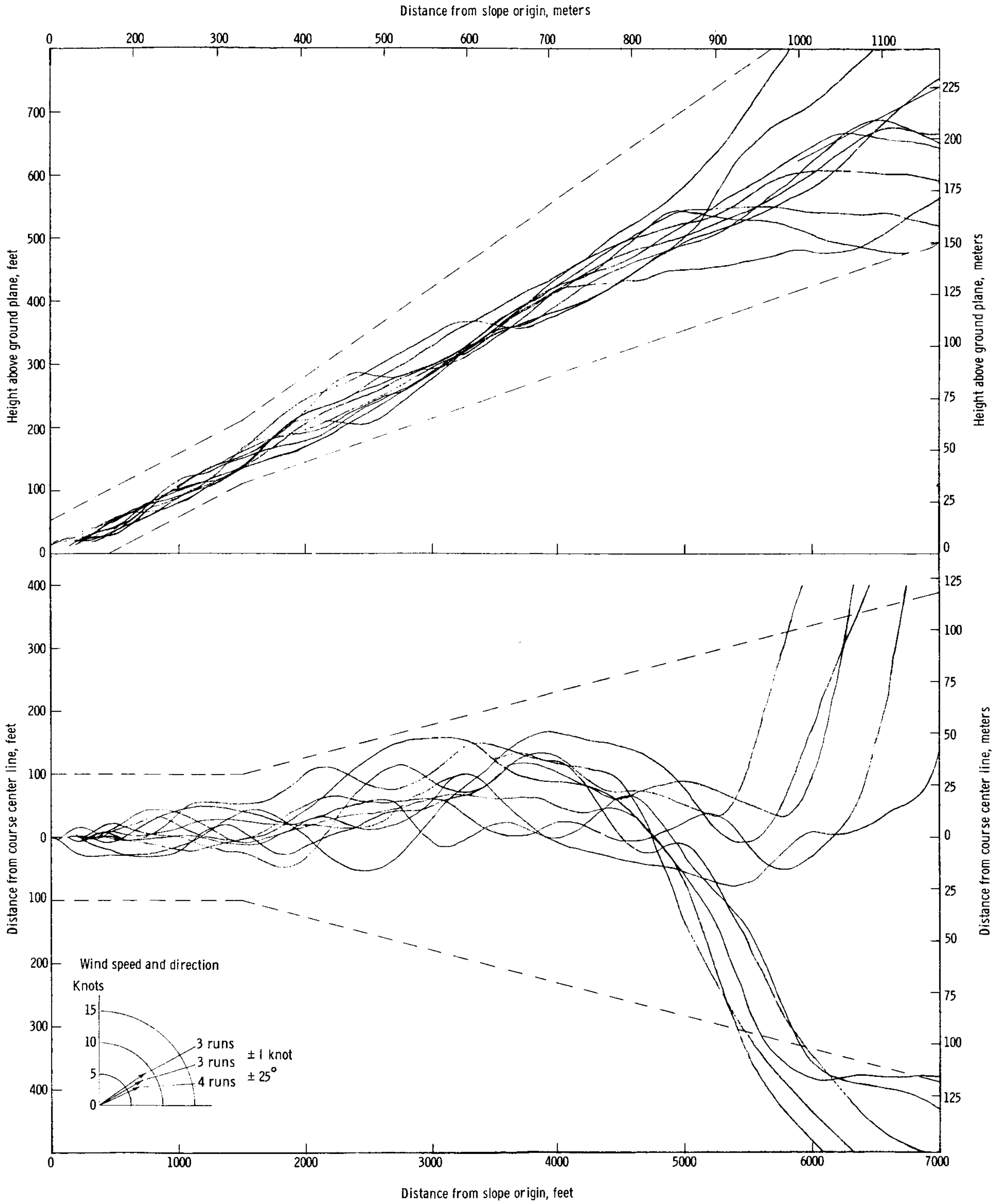
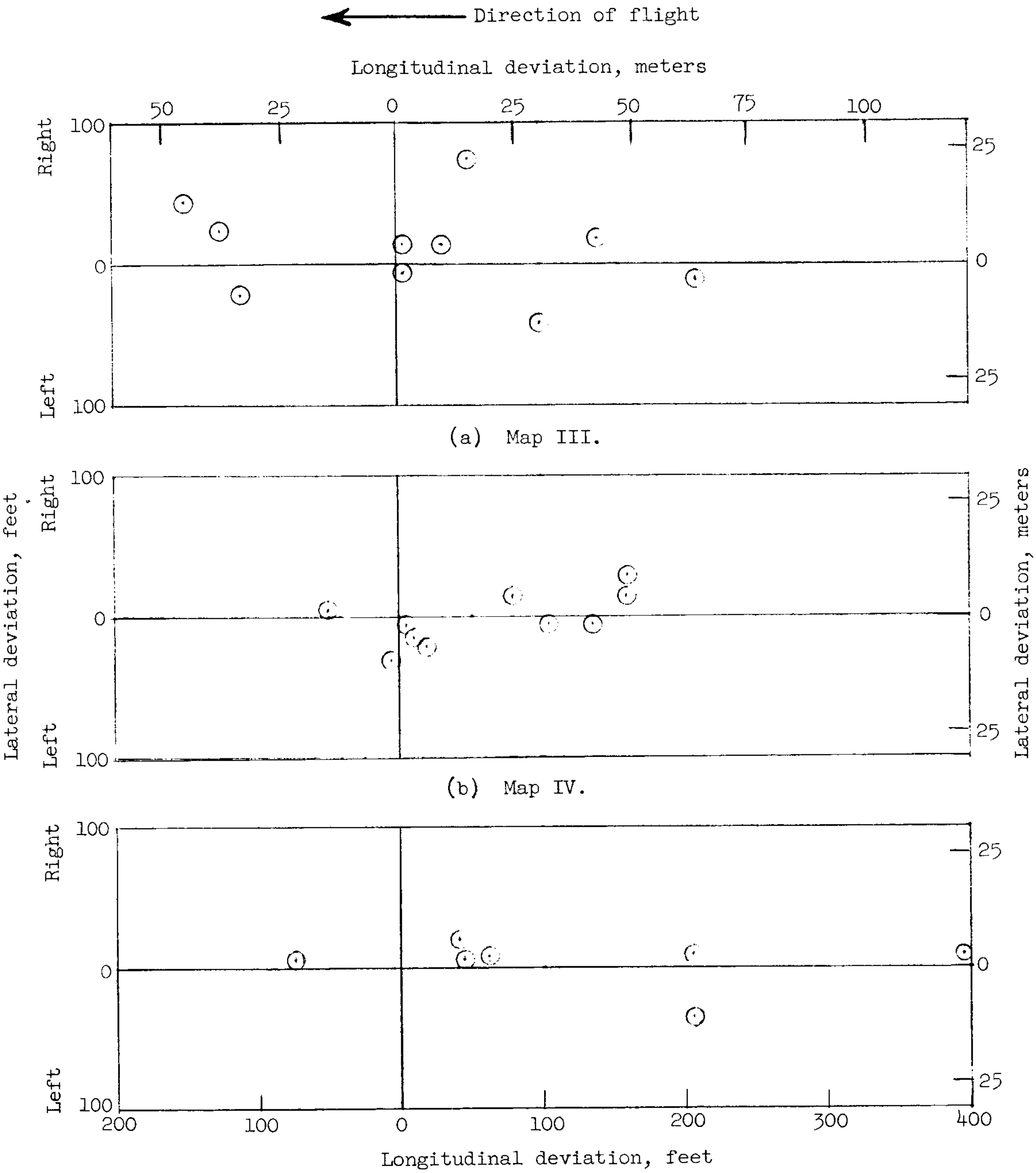


Figure 8.- Course and slope tracks for ten 30-knot approaches to 50-foot (15.24 m) breakout. Map IV.



(c) Flight-director command (ref. 1).

Figure 9.- Longitudinal and lateral deviations from prescribed 50-foot (15.24 m) breakout point. Data are from figures 7 and 8 and reference 1.

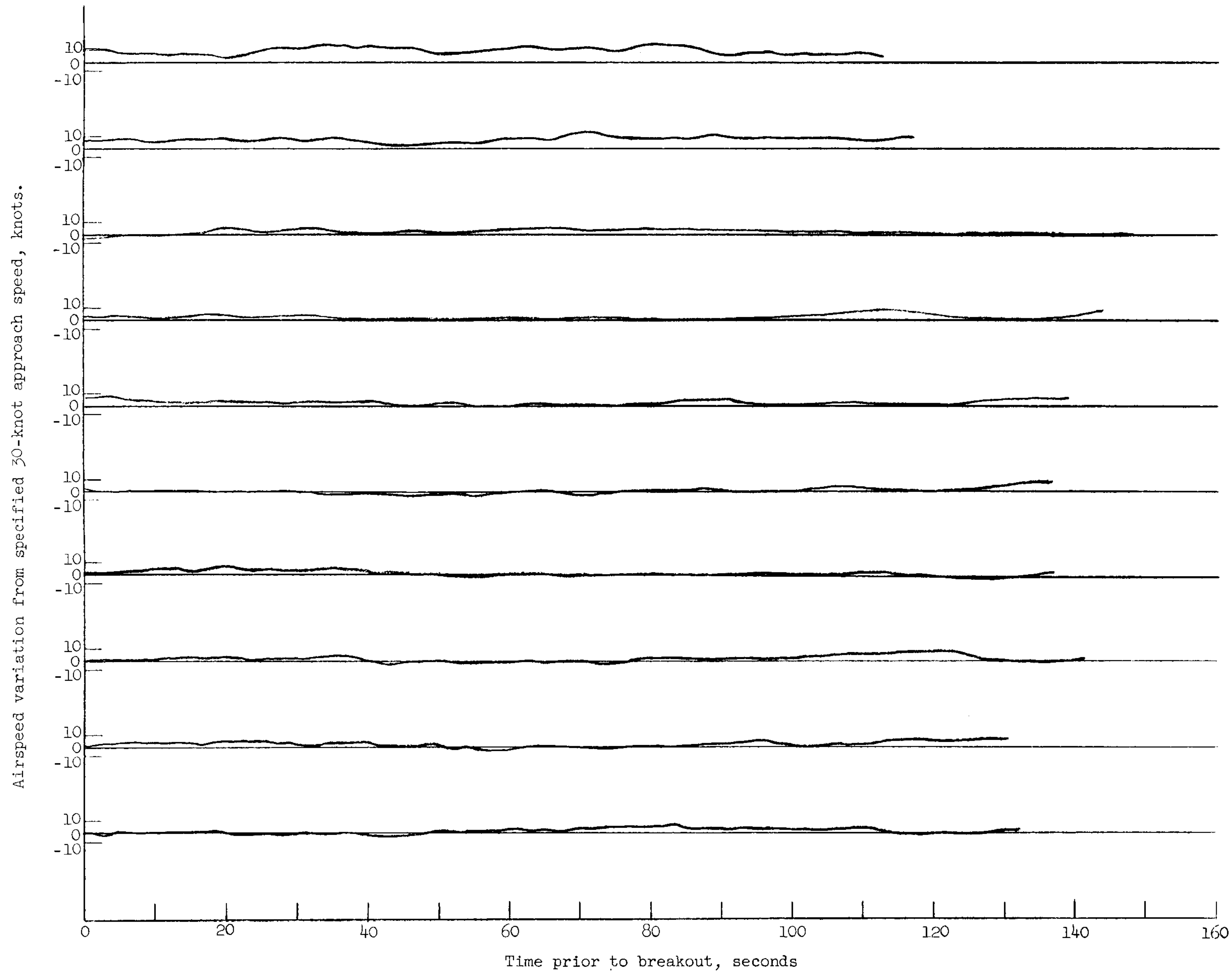


Figure 10.- Time histories of airspeed variations from specified 30-knot approach speed for range of 7000 feet (2134 m) to breakout; records are for the 10 approaches with map IV.